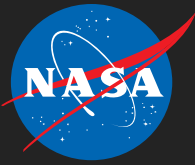


# MSFC ADVANCED CONCEPTS OFFICE DEFINING THE FUTURE OF SPACE EXPLORATION



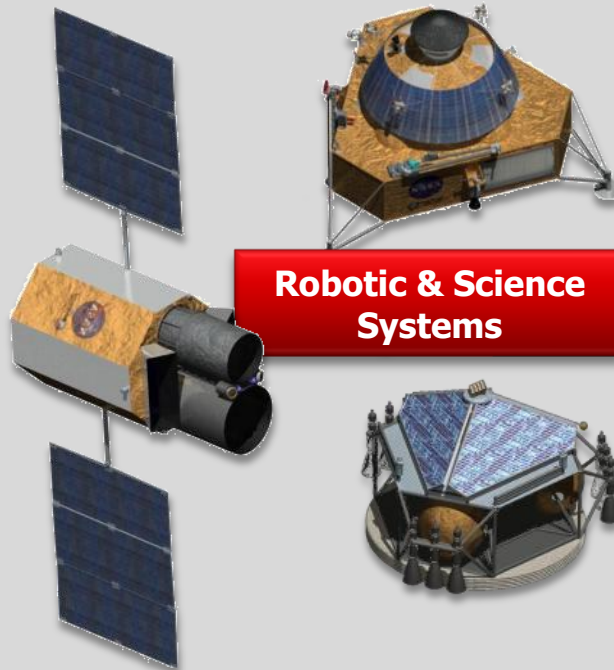


# Advanced Concepts Overview

***We Are An Office Specializing In Pre-Phase A  
& Phase A Concept Definition For Space  
Exploration Elements***



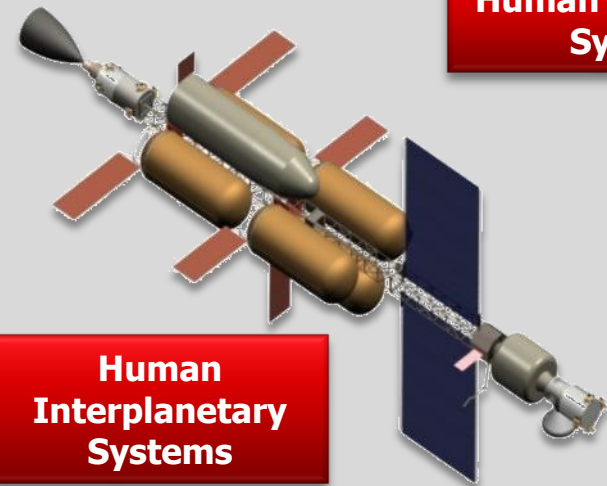
**Launch Vehicle  
Systems**



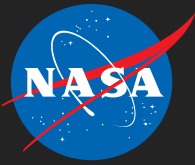
**Robotic & Science  
Systems**



**Human Exploration  
Systems**

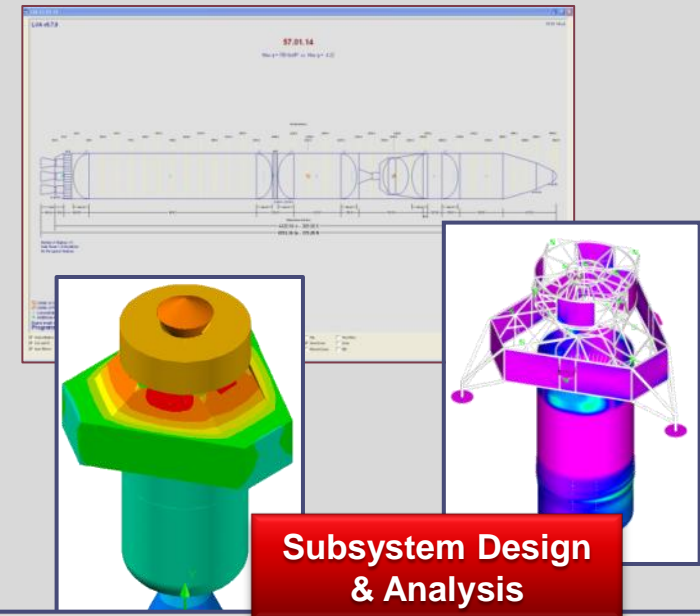
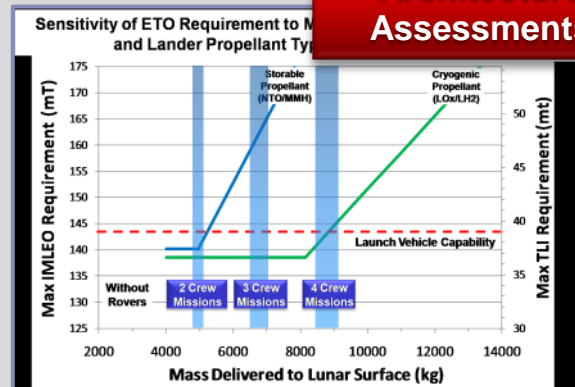
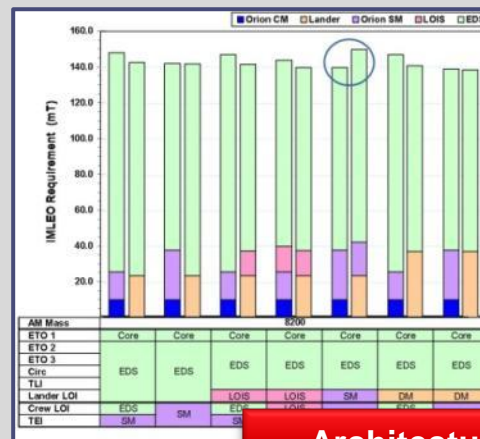
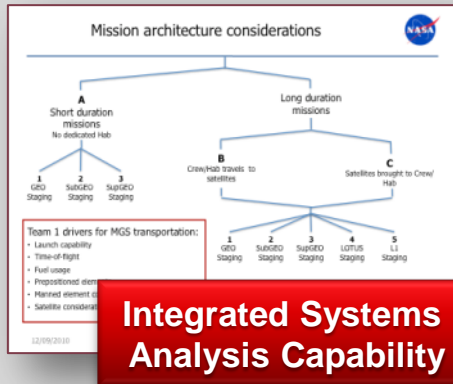


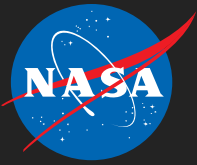
**Human  
Interplanetary  
Systems**



# Advanced Concepts Overview

***We Utilize Multi-Disciplined Teams Within the Office to Provide Fully Integrated Assessments of Missions and Their Elements***





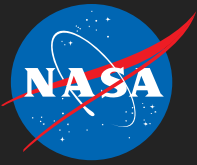
# Project & Study Highlights

## *Science & Robotic Exploration*

- ◆ Advanced X-ray Timing Array (AXTAR)
- ◆ Small Orbital Debris Detection And Tracking (SODDAT)
- ◆ Cryogenic Propellant Storage & Transfer (CPST) Technology Demonstration Definition
- ◆ Nano-Energetic Propellants
- ◆ Space Solar Power

## *Human Exploration*

- ◆ Space Launch Systems (SLS) Definition
  - ◆ Launch Vehicle Trades & Analysis
  - ◆ Architecture Definition
- ◆ Human Spaceflight Architecture Team (HAT)
  - ◆ Cryo Propulsion Stage Definition
  - ◆ Lunar Lander Definition
  - ◆ Deep Space Habitat Definition
- ◆ Manned GEO Servicing



# ACO Contributions to the Agency

HEOMD

HAT

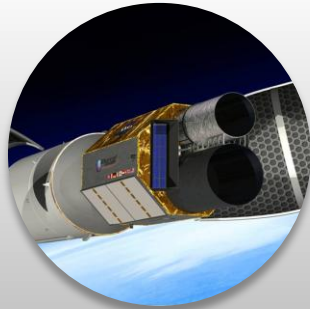
MSFC Center  
Development

MSFC Engineering  
Directorate

MSFC Science &  
Mission Systems



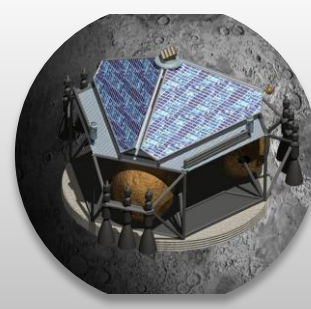
*Earth-to-Orbit  
Transportation  
System Definition*



*Earth & Planetary  
Science Concept  
Definition*



*Human Exploration  
Architecture  
Definition*



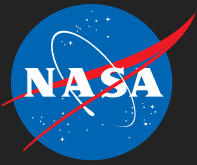
*Scientific & Robotic  
Exploration*



*In Space Element  
Definition*

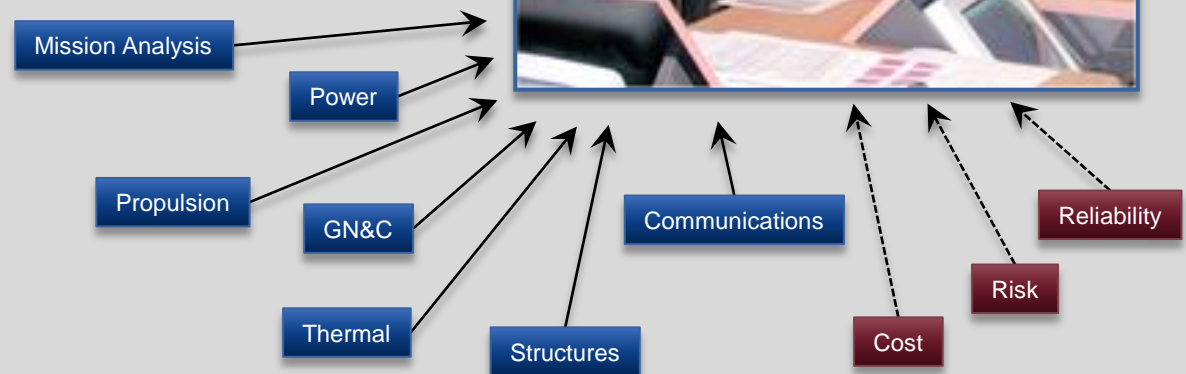
***Advanced Concepts Products Influence  
NASA Programs***

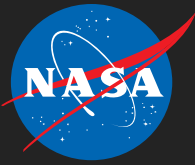




# Collaborative Design Team

- ◆ The ACO Design Teams are established, co-located teams of systems and design engineers
- ◆ Other disciplines or specific expertise are matrixed into the team as necessary
- ◆ Scientific Areas of Interest
- ◆ Programmatic Support
- ◆ Additional Discipline Support





# Design & Analysis Tools

**INTROS**

**ProEngineer**

*Advanced Concepts  
uses a suite of industry  
standard and in-house  
developed tools to  
perform analysis*

**Thermal Desktop**

**Copernicus**

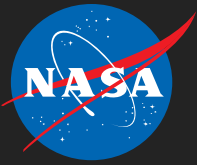
**LVA**

**3D Studio**

**POST**

**COPA**

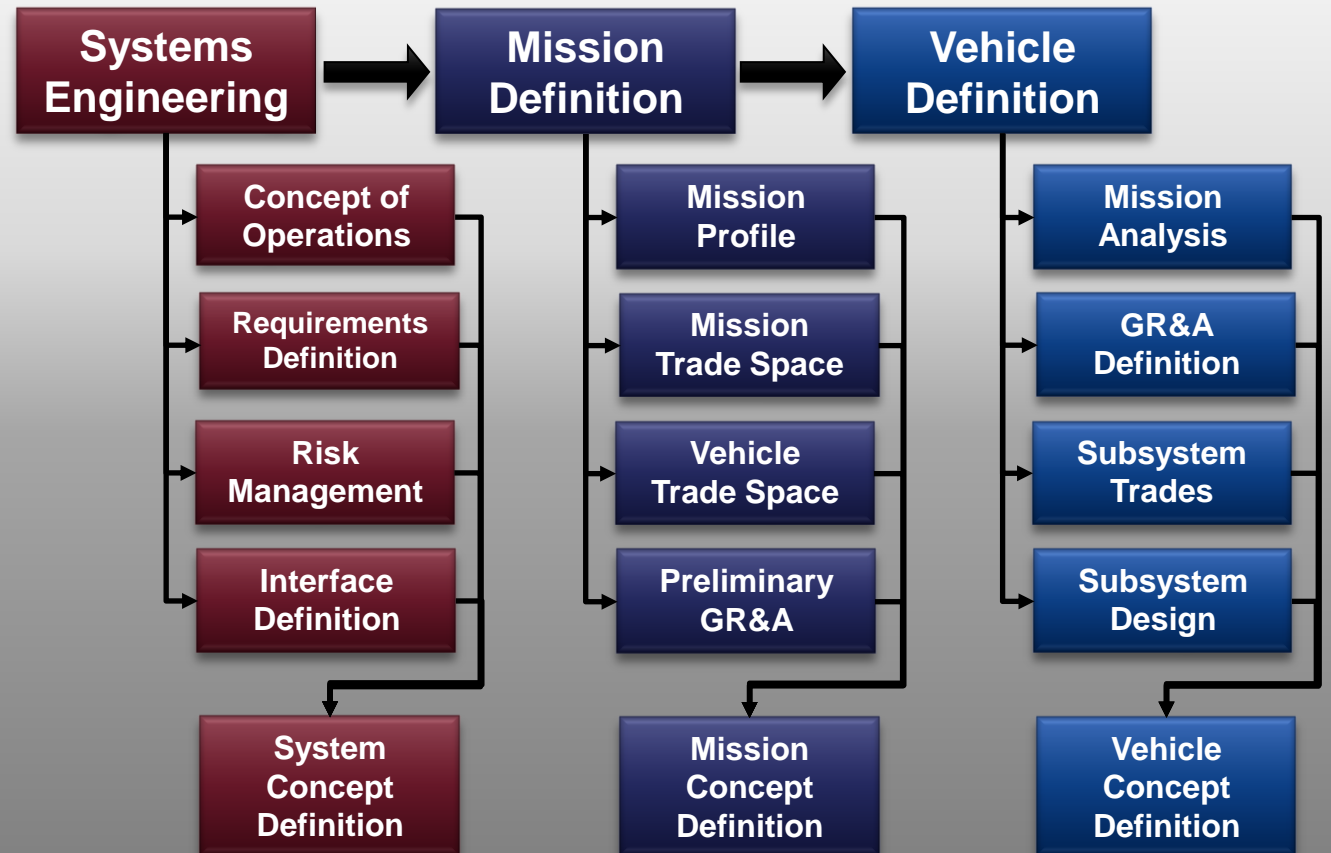
**FEMAP w/NX NASTRAN**



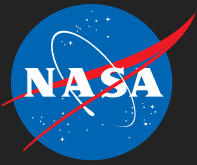
# Collaborative Design Process

## Engineering Directorate Collaborative Pre-Phase A Design Process

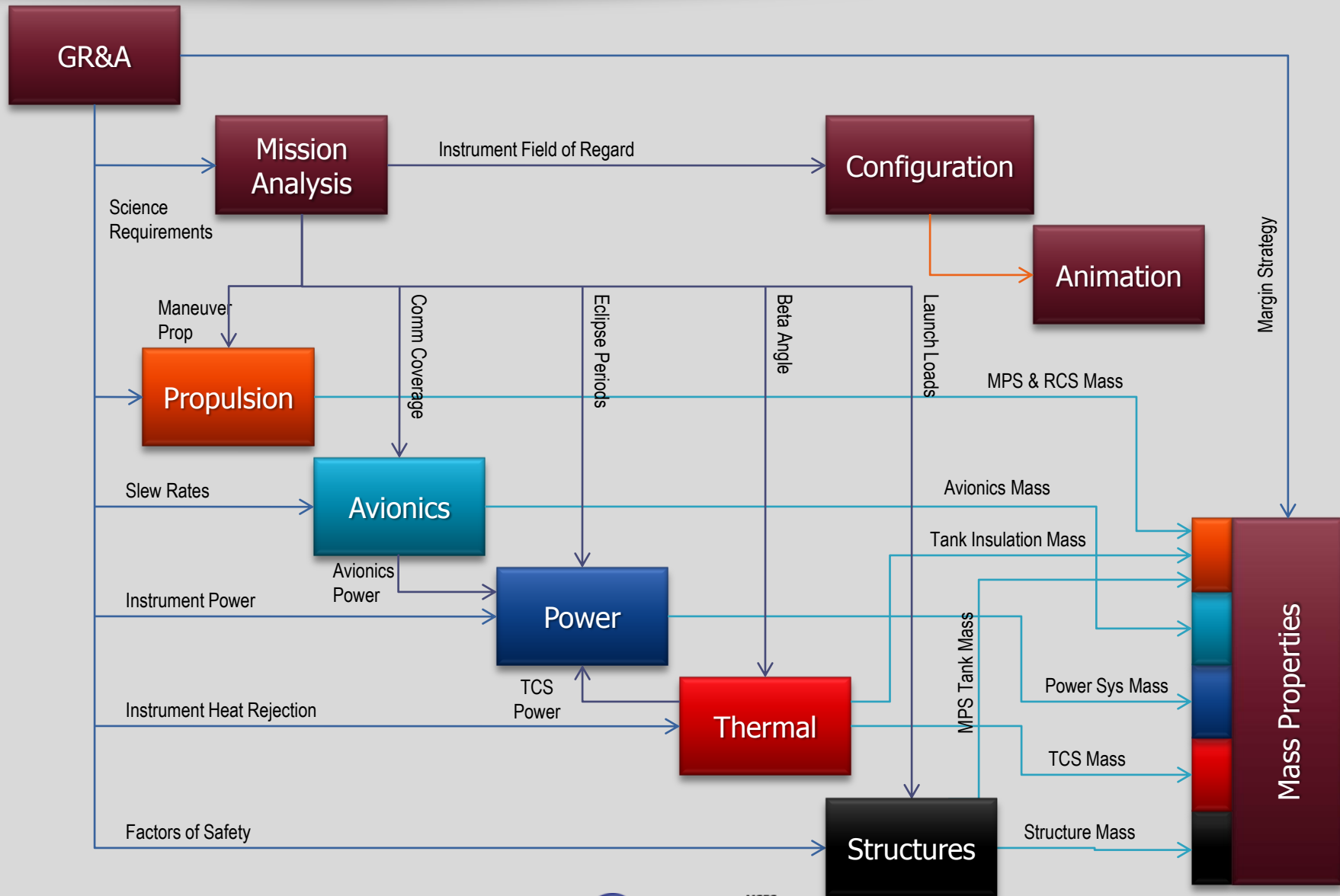
Consistent with NASA NPR 7120  
System Engineering Principles

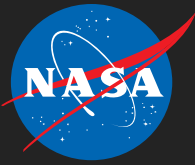






# Simplified Vehicle Definition Process

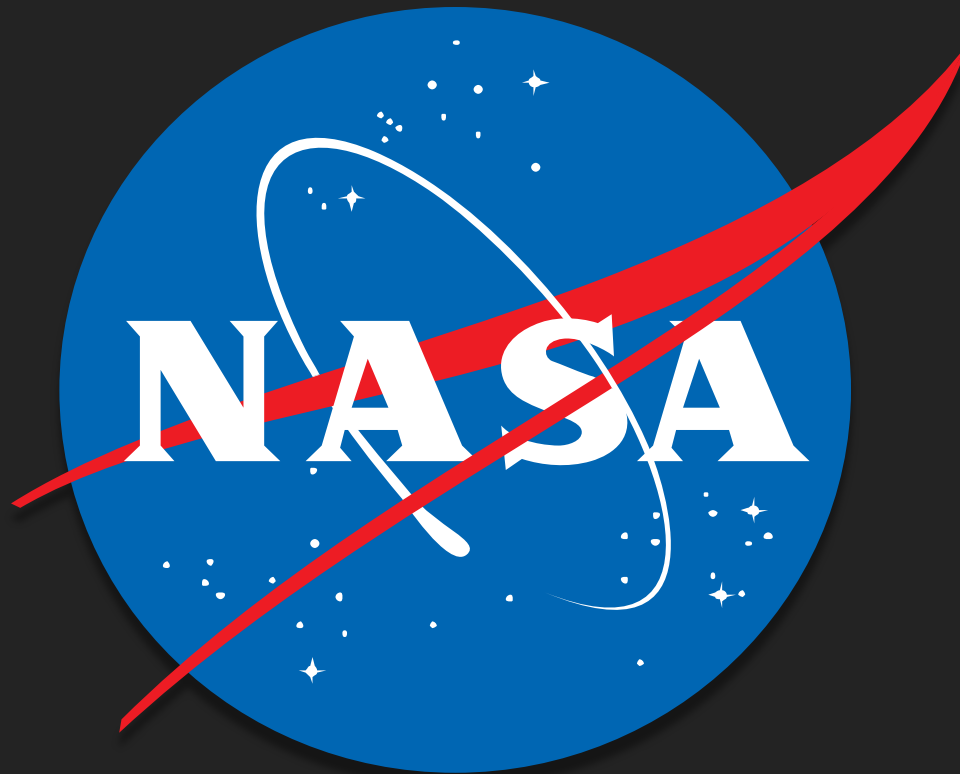


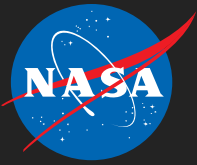


# Summary

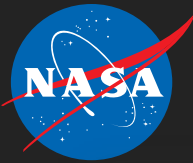
- ◆ Advanced Concepts Performs Rapid Pre-Phase A & Phase A Conceptual Design and Analysis for Space Exploration Elements
  - ◆ Collaborative Engineering Processes
  - ◆ Diverse Toolset

***Vdot's implementation will greatly enhance the capabilities of the Advanced Concepts Office***





# STUDY EXAMPLES



# Example: AXTAR Spacecraft Study



## AXTAR: Introduction



- **Customer**
  - Colleen Wilson-Hodge (VP62) and the AXTAR science team
- **Mission Description**
  - The Advanced X-ray Timing Array (AXTAR) is an X-ray observatory concept combining very large collecting area, broadband spectral coverage, high time resolution, highly flexible scheduling, and an ability to respond promptly to time-critical targets of opportunity.
  - It's mission is to probe the physics of ultra-dense matter, strongly curved space-times, and intense magnetic fields.
  - Instruments: (1) the Large Area Timing Array (LATA) is for timing observations of accreting neutron stars and black holes; (2) the sensitive Sky Monitor (SM) acts as a trigger for pointed observations of X-ray transients and also provides sensitive monitoring of the X-ray sky.
- **Mission Class: MIDEX science mission.**

AXTAR Final Deliverable, 6 May 2010 (Revised June 10, 2010)

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## Goals and Responsibilities



- **Study Goal**
  - Complete a conceptual spacecraft design to support the AXTAR science mission and determine the maximum number of LATA supermodules and Sky Monitor cameras that can be accommodated on a feasible configuration

### Responsibilities

#### Advanced Concepts Office

##### Spacecraft

- Communications
- Electrical Power
- Trajectory / GN&C
- Propulsion
- Thermal
- AR&D
- Launch Stack
- Shroud
- Integration
- Cost

##### Instruments

- Propose method to transfer heat from LATA to spacecraft thermal control system
- Determine max number of LATA modules and Sky Monitors for feasible configuration.



#### VP62



##### Instruments

- Design
- Power
- Mass
- Data requirements
- Cost (ED04/CS50 will also cost the instruments)

AXTAR Final Deliverable, 6 May 2010 (Revised June 10, 2010)

5



## Bus structure



AXTAR Final Deliverable, 6 May 2010 (Revised June 10, 2010)

Taurus II Design: Configuration

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## AXTAR: Mass Properties (Falcon 9 Concept)

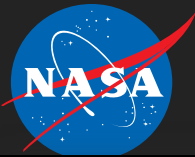


<b>4.0 Avionics/Control</b>			<b>422.53</b>
4.1 ACS (includes Reaction Wheels and Torque Rods)	1	308.98	308.98
4.2 CDS (includes Flight Computers and Data Recorders)	1	20.00	20.00
4.3 Instrumentation	1	15.00	15.00
4.4 Communications System	1	38.55	38.55
4.5 Avionics Cabling	1	40.00	40.00
<b>5.0 Thermal Control</b>			<b>53.90</b>
5.1 Multilayer Insulation/Thermal Tape	1	42.00	42.00
5.2 Thermal Filler	1	2.10	2.10
5.3 Paint/Thermal Coatings	1	9.10	9.10
5.3 Heaters/Thermostats	1	0.70	0.70
<b>6.0 Contingency</b>			<b>620.35</b>
6.1 Structure	30%		362.50
6.2 Propulsion	30%		28.40
6.3 Power	30%		66.53
6.4 Avionics/Control	30%		126.76
6.5 Thermal	30%		16.17
<b>Dry Mass</b>			<b>2688.19</b>
<b>7.0 Non-propellant Fluids</b>			<b>4.09</b>
7.1 Residual Hydrazine	1	2.09	2.09
7.2 Pressurant (GN <sub>2</sub> )	1	2.00	2.00
<b>8.0 Payload/Science Instruments</b>			<b>1797.20</b>
8.1 LATA	42	30.00	1260.00
8.2 SM	27	2.00	54.00
8.3 IDS	1	30.00	30.00
8.4 Payload Contingency (30%)		403.20	403.20
8.5 Instrument Cabling	1	50.00	50.00
<b>Inert Mass</b>			<b>1801.29</b>
<b>Total Less Propellant</b>			<b>4489.48</b>
<b>9.0 Propellant (Hydrazine)</b>	1	405.25	<b>405.25</b>
<b>Gross Mass</b>			<b>4894.7268</b>

AXTAR Final Deliverable, 6 May 2010 (Revised June 10, 2010)

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# Example: Cryostat

## CRYOSTAT Mission Overview

### DESCRIPTION

- This project will demonstrate the technologies needed to store, monitor, access, pre-position and transfer cryogenic propellants for large cryogenic propellant storage and transfer systems that will support future space mission and commercial market opportunities

### APPROACH

- Critical technologies are demonstrated in one mission utilizing one vehicle

### APPLICATIONS

- Human exploration missions beyond LEO utilizing:
  - Large cryogenic stages w/ long duration space exposures
  - Propellant transfer for the earth departure stages (EDS)
- Supporting infrastructure for commercial space options (e.g., for satellite servicing, propellant transfer, refueling depots, tourism, etc.)

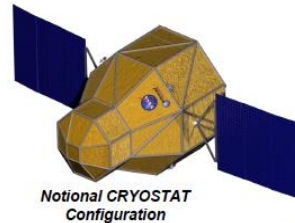
### BENEFITS

- Enabling large cryogenic propulsion stages for Human exploration
- Options for use of commercial operations to support explorations missions (through use of multiple propellant transfers)

### TECHNOLOGY ELEMENTS

- Tank Thermal Control
- Tank Pressure Control
- Cryogenic Propellant Transfer
- Liquid Acquisition
- Mass Gauging
- Leak Detection

### CONFIGURATION



## CRYOSTAT Concepts

### CPS-Lite Maximum Size (on Falcon 9 Capability)

Length: 4.6 m  
Dia.: 4 m  
LH2 Mass: 316 kg  
LOX Mass: 2000 kg  
CFM System: 3816 kg  
Bus: 3020 kg  
Total Mass: 6836 kg

### CPS-Lite Minimum Size (Based on 2 Month Mission)

Length: 4.2 m  
Dia.: 2 m  
LH2 Mass: 250 kg  
LOX Mass: 580 kg  
CFM System: 2350 kg  
Bus: 1300 kg  
Total Mass: 3650 kg

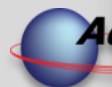
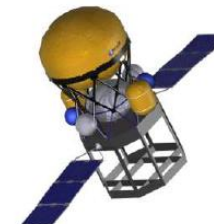
### CPS-Pathfinder (2 Month Mission)

Element	Mass
LH2	250 kg
Total CFM Payload	791 kg
Spacecraft Bus	471 kg
Launch Mass	1262 kg

Spacecraft Size  
Length = 2.4 m  
Dia. = 1.9 m



Spacecraft Bus





# Example: HEFT CryoPropulsion Stage

## Groundrules & Assumptions



- ◆ Provides  $\Delta V$  for circularization of the launch vehicle 30x130 nmi delivery orbit to the LEO 220 nmi circular orbit for itself and any other payloads manifested with it on the launch vehicle.
- ◆ CPS includes avionics, propulsion, and attitude control for automated rendezvous and docking. When rendezvous and docking with other elements the CPS can play either the active or passive role.
- ◆ CPS structure will provide adequate load bearing strength to account for its own fully loaded mass, plus the mass of any attached payloads through all phases of the mission, including launch, loiter, docking, and active thrusting.
- ◆ While loitering in-space, the CPS provides required attitude control for itself plus any attached payloads utilizing on-board RCS (storable, bi-prop system).



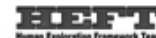
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## Groundrules & Assumptions



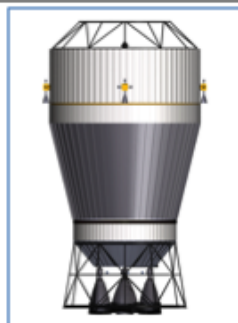
- ◆ CPS has a power generation and storage system capable of providing the necessary power for itself, plus any required attached payloads (quantity TBD) for all phases of flight. The full power generation capability of the CPS can be transferred to other elements through the forward docking IDSS/payload interface.
- ◆ The CPS Block 2 includes a long duration cryogenic fluid management system that provides 0.5%/month liquid hydrogen loss (by mass), and 0%/month liquid oxygen loss.
- ◆ During high thrust maneuvers where a Solar Electric Propulsion (SEP) stage is connected, the CPS engines must maintain a thrust to weight of the assembled elements of less than 0.1g.



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## Cryo-Propulsion Stage – Block 1



### Design Constraints/Parameters

Propellants	O <sub>2</sub> /H <sub>2</sub>
Stage PMF	0.8
Stage Diameter	7.5 m
Stage Length	18 m
# Engines / Type	4 / Altair DME
Engine Thrust (100%)	18,627
Engine Isp (100%)	448.6 sec
RCS Propellants	NTOMMH
# RCS Thrusters / Type	16 / Press-fed
RCS Thruster Isp	350 sec

### Passive Thermal Control of Propellants

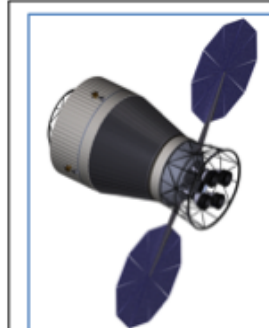
The Block 1 Cryo-Propulsion Stage (CPS-B1) is delivered to a 30 x 130 nmi insertion orbit by the launch vehicle where the CPS is then responsible for raising and circularizing itself and any payload to an orbit of 220 nmi. The non-reuseable CPS-B1 utilizes passive thermal control techniques to limit cryogenic propellant boiloff during its operation. The CPS-B1 includes avionics, propulsion, and attitude control for automated rendezvous and docking. Inert propellants are mission specific and are affected by mission duration, number of engine burns, and other mission parameters.

Category	Mass, kg
Structure	2,913
Propulsion	3,623
MPS (including tanks)	2,761
RCS (including tanks)	262
Power	147
Avionics	455
Thermal	1,691
Active CFM	-
Passive CFM	364
Vehicle TCS	728
MMOD Protection	-
Growth (30%)	2,239
Dry Mass*	9,918
Inert Mass*	2629
MPS Fuel Boiloff	49
MPS Oxidizer Boiloff	96
Non-Usable MPS Prop	1,716
Non-Usable RCS Prop	31
Pressurants	136
Total Less Usable Prop	11,847
Usable Propellant	67,897
MPS Fuel	10,266
MPS Oxidizer	56,572
RCS Fuel	392
RCS Oxidizer	647
Total Stage Wet Mass	79,844

\* Mission specific values

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## Cryo-Propulsion Stage – Block 2



### Design Constraints/Parameters

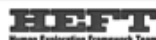
Propellants	O <sub>2</sub> /H <sub>2</sub>
Stage PMF	0.8
Stage Diameter	7.5 m
Stage Length	18 m
# Engines / Type	4 / Altair DME
Engine Thrust (100%)	18,627
Engine Isp (100%)	448.6 sec
RCS Propellants	NTOMMH
# RCS Thrusters / Type	16 / Press-fed
RCS Thruster Isp	350 sec
0.5% per month H <sub>2</sub> Boiloff	
0% per month O <sub>2</sub> Boiloff	
2 x UltraFlex Arrays (26.7 kW total power)	

### Description

The Block 2 Cryo-Propulsion Stage (CPS-B2) builds upon the Block 1 CPS but includes a long duration cryogenic fluid management system that provides 0.5%/month liquid hydrogen loss (by mass), and 0%/month liquid oxygen loss. The CPS includes avionics, propulsion, and attitude control for automated rendezvous and docking. Inert propellants are mission specific and are affected by mission duration, number of engine burns, and other mission parameters.

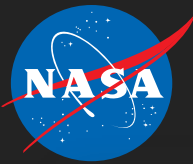
Category	Mass, kg
Structure	2,913
Propulsion	3,623
MPS (including tanks)	2,761
RCS (including tanks)	262
Power	1,600
Avionics	455
Thermal	4,657
Active CFM	2,865
Passive CFM	364
Vehicle TCS	728
MMOD Protection	382
Growth (30%)	3,050
Dry Mass*	15,383
Inert Mass*	2,229
MPS Fuel Boiloff	535
MPS Oxidizer Boiloff	-
Non-Usable MPS Prop	1,716
Non-Usable RCS Prop	31
Pressurants	136
Total Less Usable Prop	17,602
Usable Propellant	67,897
MPS Fuel	10,266
MPS Oxidizer	56,572
RCS Fuel	392
RCS Oxidizer	647
Total Stage Wet Mass	85,499

\* Mission specific values



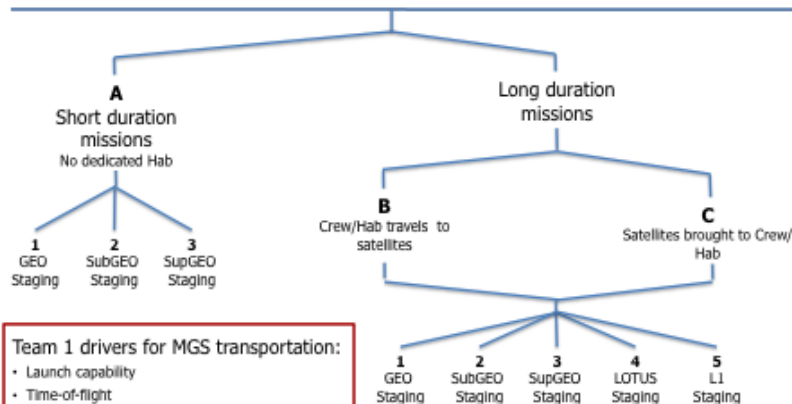
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# Example: Manned GEO Servicing

## DARPA Mission architecture considerations



### Team 1 drivers for MGS transportation:

- Launch capability
- Time-of-flight
- Fuel usage
- Prepositioned elements
- Manned element considerations
- Satellite considerations

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## DARPA Potential launch vehicles for MGS missions (1 of 2)



1 – KSC ELV performance, 200 km  
2 – SpaceX Falcon Heavy Quoted Estimate  
3–30 new X 130 mm insertion, 28.5 degrees, no margin

Planned



Launch Vehicle	Falcon 91	Falcon 9 Heavy2	Atlas 5011	Atlas 4011	Atlas 5411	Atlas 5511	Delta IV Heavy1	In-line Shuttle C3	HEFT SDV3
LEO payload (kg)	9,115	32,000	8,140	9,605	15,930	17,415	23,660	79,900	106,600
GTO payload (kg)	3,475	19,500	3,860	4,740	7,850	8,540	12,575	~37,800	51,395
GEO payload (kg)	~1,750	~9,750	~1,930	~2,375	~3,925	~4,270	6,160	~21,735	29,556

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## DARPA Potential launch vehicles for MGS missions (2 of 2)



Launch Vehicle	DIVH w/ACES US	Atlas V Phase 2	Atlas V Phase 2 w/Ares 1 2nd stage/ACES 3rd	Atlas V Phase 3 w/Ares 1 2nd stage/ACES 3rd	Ariane 5 ECA (AS w/DWIT cryo US)	Proton K	Proton M
LEO payload (kg)	35,000	77,900	80,000	120,000	20,000	20,800	22,000
GTO payload (kg)	19,500	43,200	~40,000	~60,000	10,500 (12,000 with SEC8 upgrade)	5,100	6,000
GEO payload (kg)	~9,750	24,100	~23,000	~34,500	~5,250	2,600	3,500

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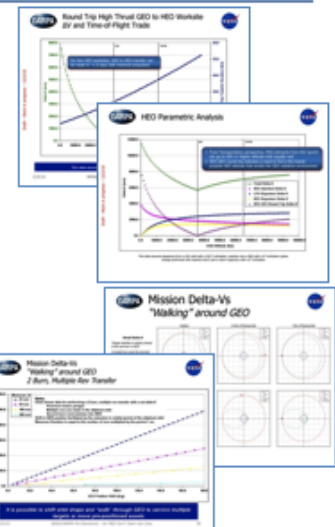
NASA/DARPA Pre-Decisional – for MGS Gov't Team Use Only

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## DARPA Astrodynamics mission architecture trades



- Radiation environment,  $\Delta V$  vs. orbital altitude:
  - EVA radiation environment improves above GEO
  - Elements transiting from LEO to GEO or HEO-65k require minimal increase in fuel usage
- Chemical propulsion vs. electric propulsion:
  - Chemical propulsion provides lower time-of-flight, electric propulsion provide better fuel economy
- Round trip  $\Delta V$  and time-of-flight, LEO to GEO/HEO-65k
- Maneuvering within GEO:
  - Relevant to ability to reach multiple satellites with either rapid response (1 day) or fuel-efficient response (weeks)

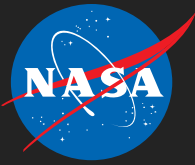


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# Example: Nano-Energetic Propellants

## Potential Vehicle Benefit

Mission	Propellant Load (kg)	$\Delta V$ (m/sec)	NEPP Propellant Candidates	Science Payload Increase (%)	
				O <sub>2</sub> /H <sub>2</sub>	HAN/H <sub>2</sub> O
Mars Astrobiology Explorer	596	419	O <sub>2</sub> / Metalized Gelled H <sub>2</sub> (MGH)	60.0	50.3
Mars Sample Return Lander	470	389	HAN / H <sub>2</sub> O / FGS-nDiamond	18.9	16.2
Mars Geophysical Network	132	296		34.4	38.6
Io Observer	989	1124		110.5	89.4
Saturn Probe	252	675		113.4	106.3

**Game-Changing**

Mission	Propellant (kg)	$\Delta V$ (m/sec)	NEPP Propellant Candidates	Science Payload Increase (%)	
				O <sub>2</sub> /H <sub>2</sub>	HAN
Mercury Lander	1969	1238	O <sub>2</sub> / Metalized Gelled H <sub>2</sub> (MGH)	51.8	-2.6
Venus Mobile Explorer	370	280		15.5	4.6
Venus Intrepid Terresa Lander	351	270		9.5	3.0
Venus Climate Mission	1432	1734		22.8	-0.4
Lunar Polar Volatiles Explorer	216	254	HAN / H <sub>2</sub> O / FGS-nDiamond	3.5	2.0
Mars Sample Return Orbiter	1573	3690		21 kg	-0.6
Jupiter Europa Orbiter	2681	2260		27.1	-2.1
Ganymede Orbiter	2664	2662		65.5	-5.0
Trojan Tour	557	1933		18.3	2.5
Titan Saturn System	2528	2377		32.8	-2.3
Enceladus Fly-by	2000	2000		55.8	-2.9
Enceladus Orbiter	2434	2881		60.9	-4.2
Titan Lake Lander	2255	2590		54.4	-3.4
Uranus Orbiter and Probe	1161	2500		23.5	0.3
Chiron Orbiter	840	2166		28.6	1.9

**Game-Changing**

Mission	Baseline Motor	Propellant Load (kg)	$\Delta V$ (m/sec)	NEPP Propellant Candidates	Science Payload Increase (%)				
					(1)	(2)	(3)	(4)	(5)
Mercury Lander	Star 48V	2076	4426	(1) DCPD / AP / nAI	-62.8	13.8	-9.1	13.8	-21.3
Lunar Geophysical Network	Star 30BP	457	2450	(2) High Solids HTPB	-19.3	17.7	1.2	15.7	-7.7
Lunar Polar Volatiles Explorer	Star 48V	2010	2455	(3) HAN/HTPB/AI	-41.0	10.1	-5.2	10.1	-13.3
Mars Sample Return Lander	Star 17A	145	1857	(4) HAN/GAP/AI					
				(5) HAN/DCPD/AI	-1.6	1.0	0.2	1.0	-0.2

## Subsystem Specific Benefit

